

# Exploring Expression of Form, Action and Interaction

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## ABSTRACT

Industrial Design is concerned with the technical design of product functions, with product meanings and with product aesthetics. Traditionally the designer has to choose and integrate materials, forms, and colours arrive at satisfactory solutions. Modern intelligent products and services add two more factors to this: mediation and behaviour. In order to make models of mediation and to study the mediation of behaviour, traditional modelling techniques, such as foam models, rendering etc. fall short. Although it is easy to make two-dimensional models of screens and front-panels and connect actions to the corresponding buttons, this approach is inadequate for new types of interfaces and behaviours which are not screen-based. Therefore we have experimented with an approach which we call 4D Sketching. The term 4D refers to the fact that it includes sketching in 3D space whereas the active behaviour adds a fourth, temporal dimension. We use foam, cardboard, a glue-gun, and other easy-to-use materials for the spatial sketching. We use a microprocessor, servo-motors and sensors to sketch active behaviour. The article describes the underlying philosophy, the technical aspects and a number of experiences gathered so-far, which include student work.

## Categories and Subject Descriptors

H5 [Information interfaces and presentation]: H.5.2 User Interfaces (*Input devices and strategies*) H.5.1 Multimedia Information Systems (*Artificial, augmented, and virtual realities*).  
General terms: Design, Human Factors. D.3.

## General Terms

Design, Experimentation, Human Factors, Languages.

## Keywords

Emotions, sketching, model making, software, product semantics, Movement, Motion, Dynamic behaviour, Robotics.

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## 1 INTRODUCTION

More and more of our experiences are mediated by intelligent digital and physically enabled products. The mediation can be from person to person, from service provider to person, or mediation over time. People are able to interact with objects over a wide spectrum of states of 'activity'; ranging from fully *off* to fully interactive, through an ambient state, a reactive, and proactive states. We claim that in order to make the richest use of the relationship between people and objects over these states of activity the object needs to be able to behave and therefore communicate at all levels possible, both on the physical and the virtual levels.

The 'nature' or 'character' of an object or thing is manifest through a number of levels of its existence: physical; static & dynamic form, behaviour, interaction mechanics, interfaces, ageing over time, colour, material, content, image, and so on. We make three assumptions:

- That all 'things' attract us according to our physical, cognitive or emotive responses to one extent or another;
- that the fuller the integrated (sensorial) interaction between us and the things we make, the stronger the relationship. We now have more channels to relate through;
- that interactions between objects and people begin and end with inputs and outputs in the physical or analogue realm and yet in between in recent times the in-outputs are transformed and translated as digital content.

If objects can behave, designers have to face the question: How can the form, empowered with behaviour, physically and digitally 'communicate' human values, culture values, societal values, tribal, community, brand values? A more practical question is closely related: What is behaviour? We may define it as the way or the mechanisms that an object goes through as it reacts to the forces put upon it. These forces exist in both the physical and in the digital form. It is not only how the object reacts, but how it initiates the reaction in others and how it in turn reacts one to another as it develops a relationship among a 'community of objects and people'. What are the protocols or rules for this behaviour in relation to others and in relation to time, how fast it reacts, how long it waits for a reaction or to respond are all ways the object can communicate through behaviour, whether its existence or behaviour is static, semi static, slow or fast movements there is always communication and response at least in one direction: from it to us.

The language available to an object to effect this communication has always been rich and includes many elements well known to us. They include; the form, the material, the colour, the texture, the scale, the sound (either as literal speech or as abstract 'music') the light which may be emitted either as image in the object or projected from it or merely emitted lighted form. How these elements are used in conjunction with each other throughout the 'use task' can be described as the syntax of the language. There are no fixed rules to govern this syntax structure in the building of the message to be communicated and there are certainly no fixed rules on how to receive or interpret the language as it is presented. This depends as much on previous experience, local context and above all the cultural value and context from which the user approaching the object.

Forms, either concrete or abstract, always carry meanings. It is the responsibility of the designer to make good use of these meanings, for example, to make products beautiful, to stress the importance of certain values, or to improve a product's ease of use and to promote or negotiate enriched experiences between people (communities) and people, people and objects and in time between objects (systems of objects) and objects or systems of objects. Design uses its own languages for this purpose, just as poets, painters, journalists, sculptures, film makes and so on do! The topic of this paper is how to explore the combined usage of form, colour and behaviour as a design language. We have to look for new ways of exploring behaviour, not separately, but in relation to traditional forms. The 4D sketching approach is helpful to find out in how far object behaviour can be used as a language and in how far it can communicate meaning.

## 2 TOWARDS RICHER MODELLING

New technologies have led to a redefinition of the concept of 'object'. Those objects, which exist only inside the computer are referred to as 'virtual', and for the time being it is still impossible to give them a physical presence, because there are not yet any materials that conform to their forms. However, these objects do live within the realms of another physicality, a host, so to speak. It is the seamless integration or convergence of the two levels of existence that design needs to begin to reconcile." One of the 'raw materials' the designer will be using in the future consists of software technology.

Whereas the 'old' designer would use 3D forms, colours and materials, we envisage a need for designers who can use communication and software since these are the 'raw materials' for the design of the virtual. Designers and students of design continue to use a multitude of different media to 'draw' out, illustrate and explore their design ideas. Two dimensional, representational techniques, using paper, pens and inks, have often proved sufficient for representing intended ideas. The introduction of computer-based mediums has accelerated and brought realistic accuracy to the process. The computer has also given rise to the integration of the two and three dimensional aspects of the 'formal' aspects.

Whereas in the past designers would typically draw ideas on paper and explored form, mass, scale and weight based issues in the third dimension, eventually bringing the two aspects together in a single object as an appearance model; today the computer enables both issues to be tackled simultaneously with the added advantage that through rapid prototyping a 'hard' representation

can be prepared with ease. The geometry data may also be used in the preparation and development of the final production piece without the need to 'rebuild' the form in the computer after the visual and feasibility testing is complete.

However, as designers now face an ever wider spectrum of 'designed' requirements, now including software behaviour, content flow, and even hardware behaviours it is imperative that new forms of drawing or even "sketching" are developed to enable the illustration, discovery and exploration of all these 'conflicting' functional needs in order to ensure the full integration of each effecting the other.

These forms of drawing need be no less 'physical' than those currently used, but probably need to merge both the physical and the 'virtual' elements simultaneously.

Having agreed this premise, the primary issues are: How does one draw this materiality? What are the media of this drawing? How do we combine all the elements without actually making the finished 'thing'? How can we make it fast enough to realise something without actually losing the idea or inspiration in the realisation process? Will the means be strong enough to encourage others to not only understand the idea but to co-laborate in its 'birth'. Are there means of drawing these new things, which enable others to join in as co-creators?

The examples in Sect 6 will demonstrate that not only have the designers used the form of drawing we call 4D sketching as a means of illustration of a mental model of an idea, but in a very rich way the drawing process have actually released ideas which have enriched and in one case enabled the designer to surpass the mental model altogether.

The three dimensional aspects of the 'drawing' is carried out using 'easy to model' traditional cardboard, foam, paper and small found objects (see Sec. 3.3). The fourth dimension or the animated life drawing is explored using simple electrical, electronic and mechatronic components coupled with the materials from the third dimension (see Sect. 4). In later stages of these projects each of the three forms of drawing are explored both simultaneously and through the same 'body' to realise each of the representation dimension integrated one to the other (see Sect. 5). Our ambition is to encourage and enable the designers and students of design to draw at all levels from the outset and even to draw as a community rather than as a single person.

## 3 THE TRADITIONAL DESIGN PROCESS: IN HOW FAR DOES IT SUPPORT EXPLORATION OF EXPRESSIVE MOTIONS?

One of the new challenges in developing the physical and virtual aspects of products simultaneously, is that—as products gain robotic characteristics—autonomous behaviour may no longer be limited to changes in two-dimensional displays, but may result in physical, mechanical, three-dimensional movements. Traditional industrial design education has taught few, if any, methods or techniques for exploring the expressiveness of such movements. Clearly, expressiveness of appearance has always been an important issue in industrial design. Techniques aimed at exploring appearance—including making moodboards, sketching and pre-modelling—have become established parts of the design

process (for an overview see Hummels et al. [4]). Expressiveness of movements, however, is a different matter. Unlike dance or theatre, traditional industrial design has had little need for exploring dynamic expressiveness. We are interested in the semantics of movement, analogous to how in the mid-eighties there was an interest in the semantics of appearance (amongst others Krippendorff & Butter [5]; Aldersey-Williams et al. [1]). In this section we explain the techniques that, in our view, are appropriate for exploring dynamic expressiveness. They are combined techniques for exploring expressiveness of movement with techniques for exploring expressiveness of appearance:

- moodboards;
- sketching;
- pre-modelling;
- acting out (full body movements);
- acting out (hand movements);
- 4D sketching.

Below we will discuss the potential role of each technique, and illustrate some techniques by work from two projects. The first project, by Feijs and Kyffin explores the potential of a telephone cradle for mediating the urgency and valence of incoming phone calls. The second project was to raise our awareness of in how far existing design techniques support exploration of dynamic expressiveness. We set up a second year bachelors project at our faculty in which we guided five students in a design process with behavioural expressiveness in mind. In twelve weeks, each student had to design a machine which was to offer its user a walnut, expressing a particular emotion in both its appearance and mechanical movement. The emotions were love, anger, enthusiasm, shyness and panic. Here we provide an overview of some of the more traditional design techniques and our understanding of how these techniques support exploring expressiveness of movement and expressiveness of appearance

### 3.1 Moodboards

Moodboards are collages of images expressing emotions through form, colour and composition. In the student project, for the most part, the moodboards were useful in exploring expressiveness of appearance in two dimensions, thus providing a stepping stone towards expressiveness of appearance in three dimensions.

### 3.2 Sketching

Sketching proved useful both for expressiveness of appearance and as a first start towards expressiveness of movement (here we mean sketching in two dimensions). For the telephone cradles sketches proved useful to explore the object-character of possible telephone cradles and to discover or reject certain metaphors in an early phase (for example sketches of the same object in active or a sleep-state). Some students sketched cartoon-like storyboards, exploring stances that their product would need to move between.

### 3.3 Pre-modelling

Pre-modelling is essentially 3D sketching. Models are made from cardboard and foam (mostly using a glue gun). Pre-models offer a way to explore both expressiveness of appearance and of movement. Some of these pre-models were expressive in a static, sculptural manner, based on the assumption that it useful to explore the relation between form and emotions before adding movements (Figure 1 and 2).

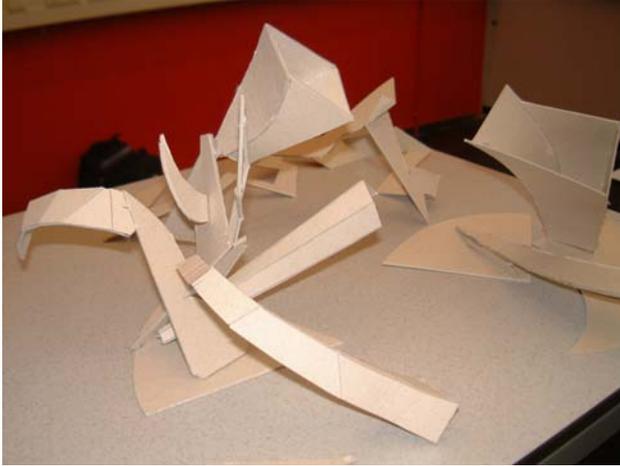


Figure 1: Exploring form and expressed emotions (1).



Figure 2: Exploring form and expressed emotions (2).

The cradles of Figures 1 and 2 were intended to convey urgency for negative and positive valences, respectively. Some preliminary investigations revealed that the valence seems to work as intended but the arousal did not (it was reported that the cartoon-like form was associated with “not serious” and “not business-like”). Although no full experiment was done yet, we found emotion self-reports using a paper and pencil version of the Self-Assessment Manikin (SAM; Lang 980) useful.



**Figure 3: Exploring form and expressed emotions (3).**

The pre-models of Figure 3 were used find out whether there was a difference in expressing anger and panic.

Other pre-models already explored qualities of movement. One student added an eccentric weight to a hand-sized egg-shaped foam model, leading to gentle, curvy and soothing movements.

### 3.4 Acting out (full body movements)

We asked students to act out emotions. Video-taping these miniature 'emotional plays' allowed students to analyze and discuss their movements and lent focus and concentration to the session. Acting out is familiar from Burns et al. [3]. In our case, the students acted out not so much the interaction between user, machine and environment but actually stood in for the machine and acted out how it would behave physically. The technique also bears resemblance to that used by Buur et al. [personal communication], though the emphasis is on the emotional content of movements rather than on their interaction style. Initially, we were somewhat hesitant to offer students this technique as we were concerned that this would lead students on an anthropomorphic route, whilst we were aiming for products that had expression appropriate to products.

### 3.5 Acting out (hand movements)

Somehow the students were aware of this too, and by their own accord they added this technique which is a modification of acting out full-body style. Instead of acting out emotions with their whole bodies, they used only their hands, again recording their movements on video tape. Excluding facial expressions already heightened the level of abstraction.

### 3.6 4D sketching

In the next section, we describe a technique developed by the second author which we propose to add to the design process of interactive products to make possible sketching in the temporal dimension. This technique moves beyond on-screen and wizard of oz simulations to physical prototypes with autonomous behaviour. The second author first applied the technique in 'phone robots' of Kyffin and his design and later the technique was explained to our students who used it to further explore the expressiveness of their 'walnut machines'.

## 4 SKETCHING IN THE TEMPORAL DIMENSION

In addition to the techniques of "acting out" at the full-body level and at the hands level, we propose to bring 3D models to life by providing them with actuators, sensors, and processing power. Such augmented cardboard and foam pre-models, could allow designers to explore physical autonomous movements in a sketchy manner. The actuators, of course, are indispensable to create motion. The sensors are needed to add interactivity or to serve as input when mediating motion. Processing is necessary to control the sequencing and the detailed timing of the actions as well as the rules that connect actuators to sensors. We discuss the actuators first (this section is more technical than the others because the technicalities matter when one must choose among alternative actuators). Although, in principle, there are no limitations to the power and the sophistication of the actuators that could be used, we restrict the discussion here to the types we have been using in at least one of our 4D sketching activities. These are:

- solenoids;
- DC motors;
- stepping motors;
- servo motors.

Solenoids are compact actuators that convert electrical energy to linear mechanical action. They contain a coil and a steel plunger that is drawn into the coil's magnetic field when energized. They have three disadvantages: their force is not constant over the stroke; most types require return springs, and they tend to get hot when activated for more than a few minutes (we once almost ruined a polystyrene foam model of an active Pacman-like game-support character because its state after the game-session was left undefined).

DC motors are very cheap, small, efficient and silent but unless a gearbox is fitted, they rotate too fast for most applications (e.g. 3000 rpm). The torque (rotational force) is inversely proportional to the speed of the output shaft. The gearbox makes them larger and noisier. Controlling their speed is not just a matter of controlling the DC Voltage; a pulse-width modulation is required instead. Controlling their position requires some kind of feedback (which is precisely what a servo-motor does).

Stepping motors are best understood as electric motors without commutators. The task of the commutators is shifted to the external motor controller, typically the processor plus some extra circuitry. The motor can be held in any fixed position as well as being rotated one way or the other. When a stepping motor is instructed to go to a certain position but the control loop is overtorqued, the motor must be reinitialised and instructed again (this is different for servomotors).

Servo motors contain a DC motor and a variable resistor measuring the rotor's position. These are mechanically and electrically configured to form a feed-back system: the motor will apply more force when encountering resistance and it will try to return to the desired position after a disturbance. A small gearbox is built-in. They are not cheap, however (the ones we used cost 40\$ each). Their control commands are in the form of repeated pulses whose width indicates the desired position (from 1.25 to

1.75 millisecond). Typically they can turn 210°. This is the preferred actuator for our 4D sketching approach.



Figure 4: Servo motor.

Several types of sensors have been used: passive infrared (detecting the heat of humans), active infrared (detecting a reflected signal), and capacitive touch sensors (based on QT310 QProx™ programmable capacitive IC). These sensors are smaller than the actuators and as such pose no space problems in the sketching. The capacitive touch sensors demand short wires, however; otherwise the wires would act as capacitors themselves (so for a sketch having four touch sensors, a small board with four 8-pin chips had to be housed inside the model).

Processing power is provided by a microprocessor board containing a 20Mhz PIC processor to be programmed in JAL (Jet Another Language). Although other processors could be used as well, such as the well-know BASIC stamp, we found PIC convenient because it had been introduced already into our Industrial Design teaching program by our colleagues of the TU/e faculty of Electrical Engineering and also because it has more than 20 configurable input-output pins. The programs can be created using any PC or laptop computer. After program compilation and download, the PIC board works in a stand-alone fashion. Downloading is through a protocol called WISP which uses the serial port. Although, in principle, the microprocessor board could be housed inside a model, until now we found it convenient to hide it just in a drawer of the demo-table or inside an exhibition console. The processor is reliable and demands no login or boot procedures (it is “turn-key”).



Figure 5: PIC microprocessor board.

The JAL language has Pascal-like programming constructs. It allows direct access to the input-output pins (this is an advantage when compared to higher-level languages such as Java, where the language’s security mechanisms implies that hardware is accessed through special interface packages). The data structures are primitive, however: bits and bytes only. To give an impression we show the program which makes a LED connected to pin a0 blink.

```
include f675_20
include jlib

var bit LED is pin_a0
pin_a0_direction = output

forever loop
    delay_100ms( 4 )
    LED = high delay_100ms( 4 )
    LED = low
end loop
```

In a typical sketching application with two servo motors, the program contains two sub-programs which represent finite-state machines, one for each servo motor. Each finite state machine inspects the relevant sensor pins, inspects some variables, makes some decisions, and writes the desired position for its servo motor to a special variable. There is one main control loop, which invokes both finite state machines. Translating the position value into input output behaviour with delays (in the 1.25 – 1.75 millisecond range) for the servo motors is done in one main loop. The approach resembles the synchronous programming style often used for so-called programming logic controllers (PLCs). The advantage is that the program looks like a set of nicely structured parallel processes, but no multi-tasking operating system is needed. The turn-around time of a typical edit-compile-run cycle is one or two minutes. In our view, this is still fast enough to call the approach “sketching”.

## 5 EXAMPLES AND EXPERIENCES

### 5.1 Phone cradles

The 4D sketching technique has been used in the (ongoing) telephone cradle project to explore whether an active cradle can express emotions. The 4D sketch of Figure 6, is quite capable of expressing “joy” through wobbling (it is kind of top-heavy and therefore the base wobbles too).

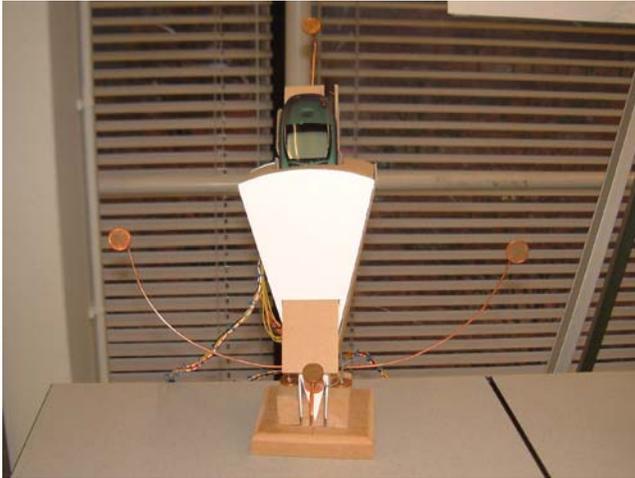


Figure 6: Active telephone cradle with wobble movement.

The models of Figures 6 and 7 have also been used to explore interaction. The model of Figure 6 has four touch-sensors. In each case the phone will move towards the user touching a sensor. Each the cradle has a lift; so when in Figure 6 the upper touch sensor is touched, the phone comes out whereas when the lower touch sensor is touched the phone moves back inside the cradle. The other model, shown in Figure 7, has just one sensor for the lift instead of two; the question we explored was whether users would recognize the “logic” of this second model, where the sensor works as a toggle switch (most test subjects had no difficulty with guessing or grasping the toggle behaviour). But it also became clear that involving test subjects demands a clear context or useful application.

Therefore in the student projects, clear choices for the context were made by us from the very beginning. The object was to perform a simple but useful function: to offer a little food. Then the students decided that this was to be a walnut.

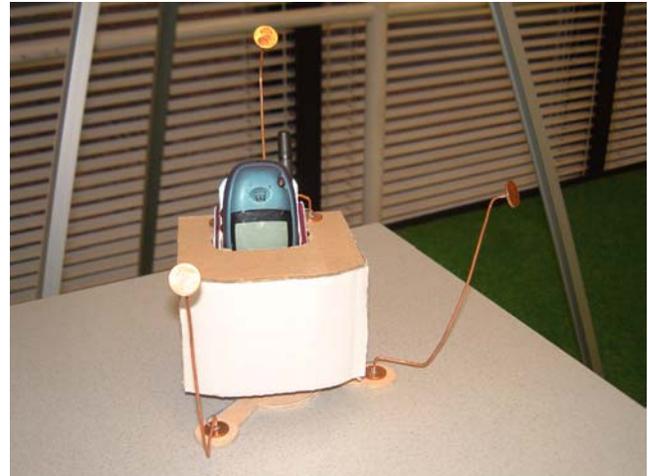


Figure 7: Active telephone cradle with twist movement.

Here we describe the design rationale and the characteristics of the five walnut machines.

### 5.2 Crack (anger) -design: Rombout Frieling

Frieling describes anger as a contrast between inside and outside, of initially cropped up inner tension against the outside world. Anger may change one's appearance rapidly and unpredictably, through fast and powerful motions in a trend of escalation. At the climax of one's anger, there may be a kind of anger overflow.

Frieling translated this description into 'Crack', a spherical machine whose shell consists of five blades with serrated edges. Initially, Crack's shell is fully closed with only the blood red, serrated spaces between its blades indicating its unrest. When approached, Crack lashes out at its user through increasingly large movements of one randomly chosen blade at a time. Finally, Crack totally cracks open into an aggressive angular, blood-red shape and ejects the walnut vertically.



Figure 8: Crack, the angry walnut machine (closed).

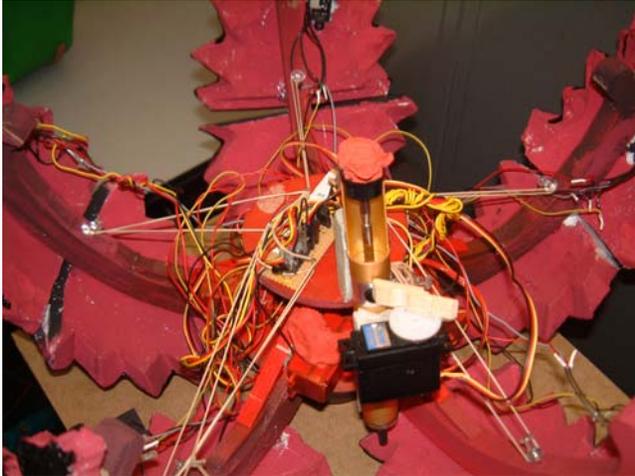


Figure 9: Crack, the angry walnut machine (open).

### 5.3 Dolly (love) - design: Jan Hoefnagels

In showing love or affection, one can do anything from comforting, via playing with, to teasing the loved one. Hoefnagels translated love into a machine called Dolly which has a wooden, smoothly polished, organic body. Dolly exhibits smooth and slow movements, intended to resemble a comforting caress. The movements curve and turn and topple past the user, giving an impression of teasing, of playing with or nuzzling up to him or her. Finally, eight bead-terminated pins slowly expand from Dolly's main body, offering the user the walnut.



Figure 10: Dolly, the walnut machine in-love (nut still inside).



Figure 11: Dolly, the walnut machine in love (nut coming out).

### 5.4 More Walnut machines

*Emotion: Enthusiasm.* Ralph Zootjes' model is used to explore expressing the emotion enthusiasm. His description of this emotion contains several stages. First, there is a suspense stage in which one expects an event that would be very advantageous. Second, one becomes more active and interested, concentrating on whether the event is going to happen or not. Then, as it is very likely for the event to happen, the excitement builds up, one starts moving more, thus letting out some of the energy that has gathered inside. Finally, the real enthusiasm bursts out. From various observations (people watching football matches, happy dogs), Zootjes concluded that there are many movements with high frequency and low amplitude to begin with but that enthusiasm often ends with very intense, large movements. Zootjes implemented these ideas into Phunx, a bright red and green coloured machine of organic form. Initially, Phunx slowly 'wags' its red top. When approached, it starts wagging faster. Finally, it lifts its white 'walnut scoop' in three quick, increasingly large movements, leading to the walnut being launched in the user's direction.

*Emotion: Panic.* Dirk Volman noted the following dynamic characteristics of panic. Firstly, one's movements spring from a single point. Secondly, the movements lack focus, because one wants to do things all at once, worsening one's panic only further. And thirdly, a movement creates a counter-movement because one wants to do everything at once and because one doubts the initial move was effective. And each counter movement creates a counter movement which creates a counter movement etc. etc. Finally, one startles again as one realizes one's problems are solved after all. Volman translated these characteristics into a semi-spherical machine called Caos. Caos violently moves random sections of its shell outwards and retracts them again, to finally extend all of them simultaneously. The nut rolls out in a rather uncontrolled manner and, after a short break, Caos retracts all its moving parts and comes to rest.

*Emotion: Shyness.* Melika El-Massoudi noted that shy people first turn away from the requesting user, often shielding their face with one hand, blushing and hesitating between doing nothing and fulfilling the request. Her machine consists of two transparent semi-spherical plastic shells in whose center the walnut lies. As the user approaches the machine, the shells turn their back on the

user, showing a different colour. They then move between shielding and exposing the walnut to, finally, fully expose it to the user.

## 5.5 General observations

On the basis of the given examples and experiences, a number of general observations can be made. First, it is absolutely worthwhile to create models which exist in the physical dimensions of the real world, not just 3D simulated in Virtual Reality. The point is that the interaction takes place by the user's real body in a multi-modal way. The sensors are not abstract buttons: the user really feels the touch button and the user notes that the IR sensors, depending on their type, do or do not have a directional sensitivity. Moreover, the sensors may move themselves relative to the phone or the nut.

Secondly, it became clear that form, colour, motion and even sound are hard to separate. In Crack and Caos these were designed to re-enforce each other (the snapping sound of solenoids fits well with panic); the surprise-effect this had on test subjects was enormous.

Thirdly, we found that a well-defined *context* was indispensable when entering a rational dialogue with a user or a test-subject. On the other hand, even without proper context, observers were intrigued by any interaction behaviour or autonomous behaviour of the models, except for simple and predictable behaviour.

Finally, we found that there are basic laws of object motion that emerge during 4D sketching but that are easily overlooked when working in 2 or 3D. In particular, any finite translation or any rotation of less than 360° has sooner or later to be followed by a movement in the opposite direction. For example, the blades of Crack move outward very fast, as a part of its expression of anger; but when folding-in gently, they weaken the anger. But closing fast again makes the expansion and the contraction symmetric, which is also not the designer's intention (for anger one needs the aggressive expansion). This type of problem continues to exist when there are several parallel, independent finite translations or limited rotations (like the four blades). But it is possible to find ways out of this dilemma when two movements are coupled (like the rotation and translation of Dolly).

## 6 EVALUATION AND OUTLOOK

We described how we and our students made the leap towards sketching in the temporal dimension. As we are based at a technical university, we are interested in letting students gain proficiency in integrating technology in a practical, hands-on manner, thus creating a new designer 'breed' that can move beyond static models and on-screen simulations towards working, mechatronic prototypes.

It was possible to "package" the 4D sketching approach by instructing the students on the acting-out techniques (Sect. 3.4) and by providing them with the materials shown in Figures 4 and 5 as a part of a two-hour demo/instruction session (the default was two servos, a PIC and a sample program; other actuators and sensors were dependent on each student's own initiative). Once the technicalities of 4D sketching are mastered, creating a new model from scratch takes less than four hours. Modifying an existing model for exploration purposes is a matter of minutes.

Let us return to the question from the introduction: How can the form, empowered with behaviour, communicate human values, culture values, societal values, tribal, community, brand values? It has become clear that objects can express at least basic emotions through movement. The 4D sketching technique is useful as a tool to explore basic emotional expressions and at least promising to explore the next levels of complexity, mediating values.

## 7 ACKNOWLEDGMENTS

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